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EFFECT OF PROLONGED SPACE FLIGHT ON CARDIAC FUNCTION AND DIMENSIONS

*Walter L. Henry, M.D.; Stephen E. Epstein, M.D.; James M. Griffith,
Robert E. Goldstein, M.D.; and David R. Redwood, M.D.
National Institute of Health, Bethesda, Maryland*

ABSTRACT

Echocardiographic studies were performed preflight 5 days before launch and on recovery day and 1, 2, 4, 11, 31 and 68 days postflight. From these echocardiograms the following measurements were made:

- ° left ventricular transverse dimension at end-diastole,
- ° left ventricular tranverse dimension at end-systole,
- ° ventricular free wall thickness at end-diastole.

From these primary measurements, left ventricular end-diastolic volume, end-systolic volume, stroke volume, and mass were derived using the accepted assumptions. Preflight measurements in the Commander revealed the left ventricular end-diastolic volume, stroke volume, and mass to be at the upper limit of normal, while those of the Scientist Pilot and Pilot were increased significantly above the normal range. These findings in the Scientist Pilot and Pilot resemble those seen in trained distance runners. Wall thickness measurements were normal in all three crewmembers preflight. Postflight basal studies were unchanged in the Commander on recovery day through 68 days postflight. In both the Scientist Pilot and Pilot, however, the left ventricular end-diastolic volume, stroke volume, and mass were decreased slightly. These decreases were noted on recovery day through 11 days postflight but had returned to near normal by 31 days postflight. Wall thickness measurements were unchanged. Left ventricular function curves were constructed for the Commander and Pilot by plotting stroke volume versus end-diastolic volume. In both astronauts, preflight and postflight data fell on the same stright line demonstrating that no deterioration in cardiac function had occurred. These data indicate that the cardiovascular system adapts well to prolonged weightlessness and suggest that alterations in cardiac dimensions and function are unlikely to limit man's future in space.

INTRODUCTION

Future space programs call for the exposure of man to prolonged periods of weightlessness. From previous NASA studies of astronauts returning

from relatively brief duration space missions, it is clear that profound but apparently reversible changes occur in various body functions. However, the effects of prolonged weightlessness on cardiac structure and function is largely unknown. Several observations have raised the suspicion that the heart might be affected adversely. These include:

- ° heart size - as determined radiographically the heart is smaller immediately postflight as compared to preflight,
- ° postural hypotension - occurs early postflight, and
- ° compared to control preflight studies, cardiac output during exercise often is reduced shortly after splashdown (1).

One of the problems in assessing the significance of diminished heart size, postural hypotension, and reduced exercising cardiac output is that space flight results in a decreased blood volume and this may cause a diminution in cardiac filling. Since the magnitude of most parameters of cardiac function is dependent on left ventricular end-diastolic volume (*i.e.*, left ventricular end-diastolic fiber length), deviations from normal, without reference to existing left ventricular end-diastolic volume, may merely reflect diminished cardiac filling rather than a primary aberration of cardiac function (2). By taking advantage of the capabilities of echocardiography to measure non-invasively left ventricular volume, stroke volume, and ejection fraction, (3-8) and of the fact that the astronauts were routinely subjected to lower body negative pressure (whereby cardiac filling is progressively decreased), we were able to construct classic ventricular function curves noninvasively, thereby obviating the difficulties encountered in comparing cardiac function at different end-diastolic volumes preflight and postflight. In this manner, the effect of an 84-day period of weightlessness on cardiac structure and function was evaluated in the Skylab 4 astronauts.

METHODS

Equipment and Technique

Studies were performed with a standard transducer (2.25 megahertz, 10 centimeter focus, 1.25 centimeter diameter), and a modified commercial ultrasound unit. The ultrasound signal was connected via a custom-built video amplifier to a strip-chart recorder and recorded continuously on light-sensitive paper. The T-scan technic was used to visualize the ventricular septum and posterobasal left ventricular wall (9). The thickness of the ventricular septum was measured inferior to the distal margins of the mitral leaflets. Posterobasal left ventricular

free-wall thickness was measured with the transducer oriented so that part of the ultrasound beam was reflected from the posterior mitral leaflet. Both thickness measurements were made just before atrial systole. Left ventricular transverse dimensions at end-diastole and end-systole were measured using the T-scan technique to identify maximum transverse dimension just caudal to the tip of the mitral leaflet (fig. 1). Left ventricular volumes were estimated by cubing the left ventricular transverse dimensions (3-5). Stroke volume was calculated by subtracting the end-systolic volume from the end-diastolic volume while ejection fraction was determined by dividing stroke volume by end-diastolic volume (3, 4). Left ventricular mass was calculated by the method of Troy *et al.* (10).

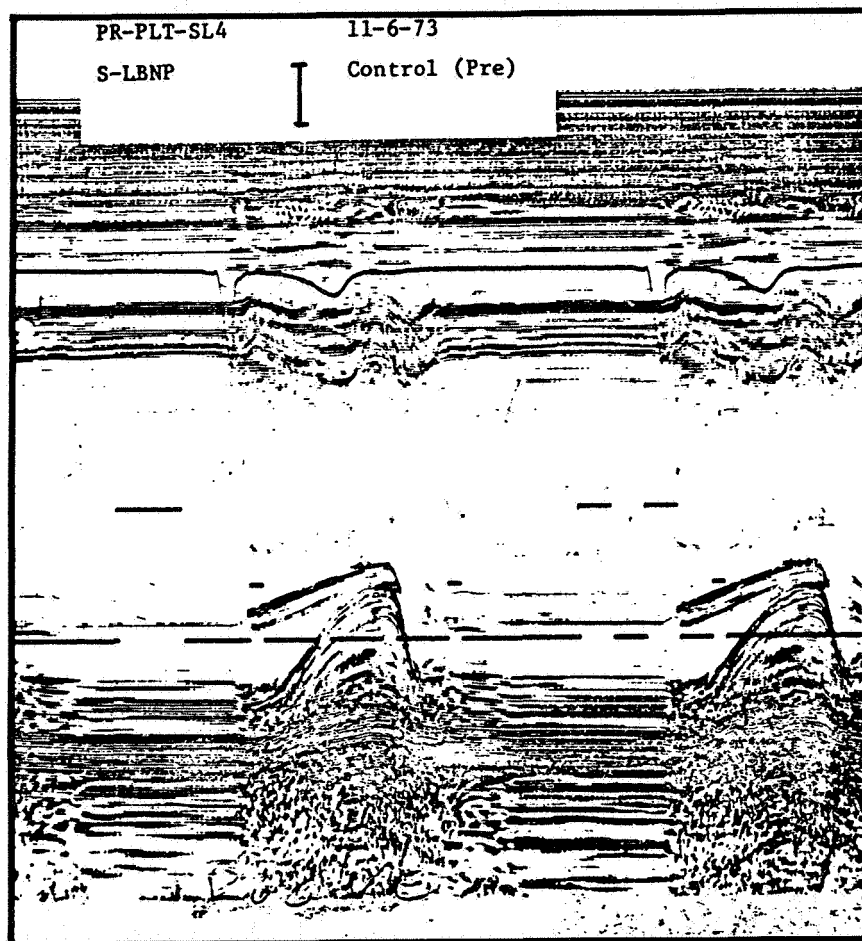


Figure 1. Measurement for left ventricular dimensions at end-diastole and end-systole, Skylab 4.

Study Protocol

Echocardiographic studies were performed with each Skylab 4 astronaut supine and rolled slightly onto his left side. Data were collected preflight on day 5 and postflight on recovery day and days 1, 2, 4, 11, 31 and 68. On each of these days a standard procedure was followed. First, control measurements were made prior to the standard protocol for application of lower body negative pressure. The same measurements were repeated five minutes after the end of the standard lower body negative pressure protocol, and successively followed by an echo devoted lower body negative pressure study which consisted of seven consecutive 1-1/2 minute periods. Control values were obtained during the first period. The middle five periods occurred during the application of an increasing amount of lower body negative pressure, beginning with -8 mm Hg, proceeding through -16 mm Hg, -30 mm Hg, -40 mm Hg, and ending with -50 mm Hg. A post lower body negative pressure 1-1/2 minute control period followed the release of the -50 mm Hg negative pressure. Echocardiographic data were recorded during the final 30 seconds of each period. The echocardiograms from each astronaut were randomized and coded so that the investigator who derived the dimensions was unaware of the day the data were collected. In addition to the echocardiographic data, systemic blood pressure (obtained with an automated sphygmomanometer system) and heart rate were recorded.

RESULTS

Control Values

Figure 2 is a plot of the estimated left ventricular volume at end-diastole in milliliters versus time in days for all three astronauts. Preflight, the Scientist Pilot and Pilot had volumes that were above the normal upper limit of 141 milliliters; immediately postflight, the left ventricular end-diastolic volume was reduced by 15 percent in these same two astronauts. This reduction persisted through day 11 postflight but had returned to near preflight values by the postflight 31-day study. Left ventricular end-diastolic volume was altered little in the Commander.

Preflight left ventricular wall thicknesses were as follows: Commander: septum 10 millimeters, posterior wall 11 millimeters; Pilot: septum 10 millimeters, posterior wall 10 millimeters; Scientist Pilot: septum 11 millimeters, posterior wall 11 millimeters. These values were all within the normal range of 9 to 12 millimeters and were unchanged postflight.

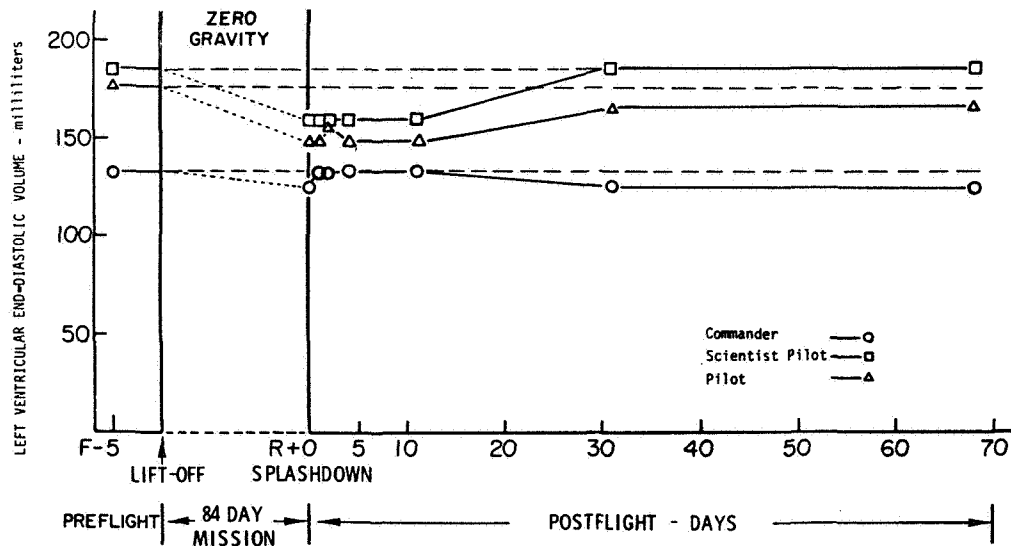


Figure 2. Estimated left ventricular volume at end diastole in milliliters vs. time, Skylab 4.

Figure 3 is a plot of estimated left ventricular mass in grams versus time in days for the three Skylab 4 astronauts. Preflight, all three were at or above the upper normal limit. Postflight, on recovery day the mass was slightly (8 percent) reduced in the Scientist Pilot and Pilot. These reductions persisted through day 11 postflight but had returned toward the preflight values by the thirty-first day postflight.

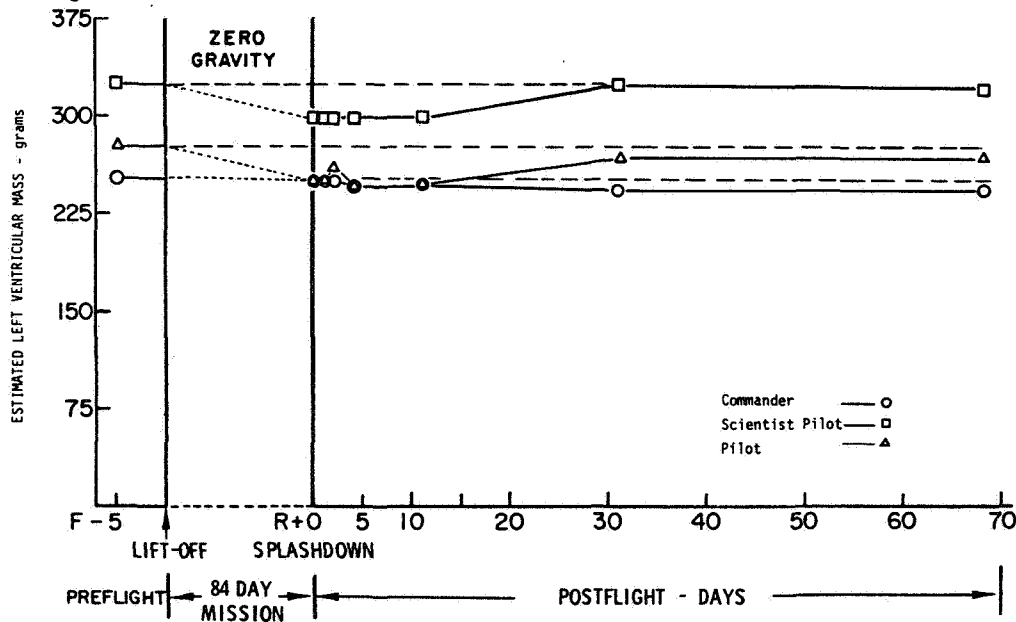


Figure 3. Estimated left ventricular mass in grams vs. time in days, Skylab 4.

Stroke volume in milliliters per beat is plotted versus time in days for all three Skylab 4 crew members in figure 4. Compared to normal values, the preflight volume of the Scientist Pilot and Pilot were significantly elevated, while that of the Commander was within normal limits. Postflight, stroke volume diminished in the Scientist Pilot and Pilot and was unchanged in the Commander. The reduction in stroke volume persisted through day 11 postflight but had returned to near preflight values by 31 days postflight.

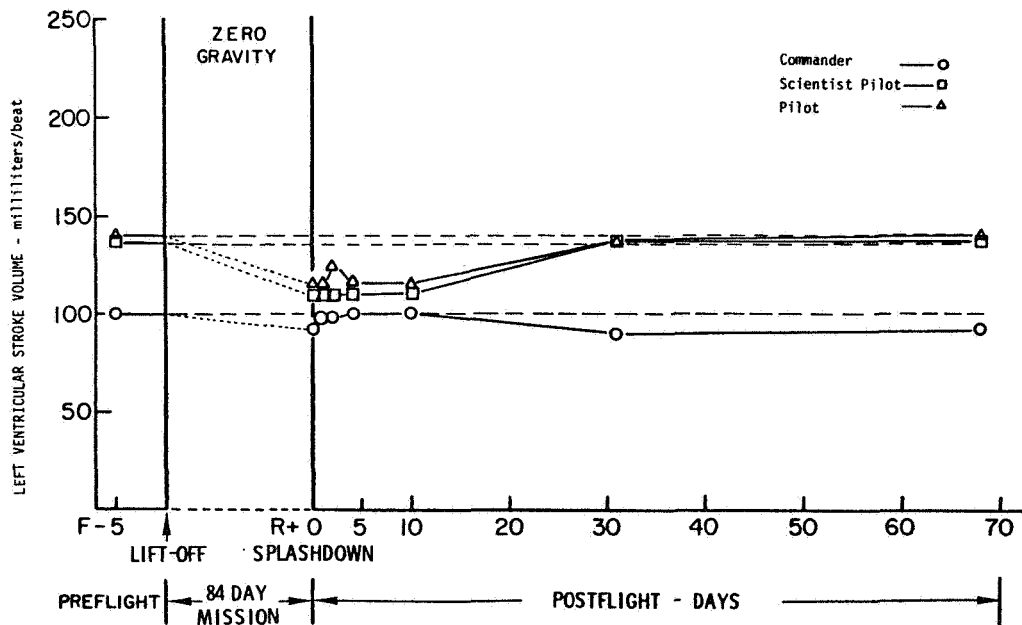


Figure 4. Stroke volume in milliliters/beat vs. time in days, Skylab 4.

Lower Body Negative Pressure Data

Satisfactory echocardiographic data were obtained during the echo-devoted lower body negative pressure protocol for the Commander and Pilot but not for the Scientist Pilot (tracings from the Scientist Pilot were of marginal quality, probably due to chest wall configuration).

Figure 5 is a plot of the left ventricular end-diastolic volume (solid line) and the stroke volume (dotted line) at the various levels of lower body negative pressure for the Pilot preflight. Similar curves were constructed for the Commander preflight and for both the Commander and Pilot postflight.

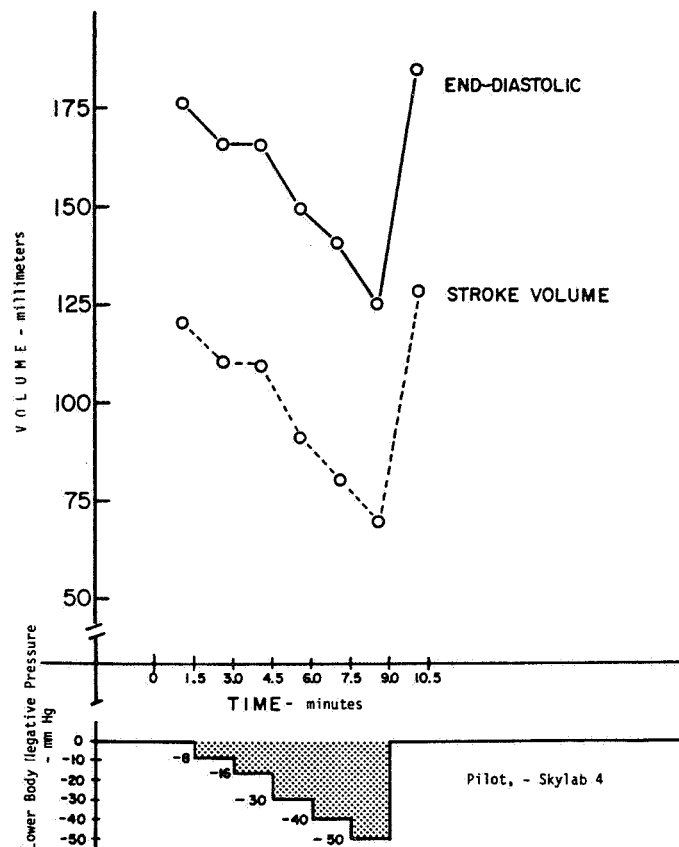


Figure 5. Left ventricular end-diastolic volume and stroke volume at the various levels of lower body negative pressure, Pilot of Skylab 4.

Using these data, ventricular function curves were constructed by plotting left ventricular end-diastolic volume versus stroke volume for the Commander (fig. 6) and the Pilot (fig. 7). Preflight values are shown by the solid lines and the immediate postflight data by the dotted lines. These figures illustrate that no deterioration in ventricular function occurred since the preflight and postflight data fall on the same straight line.

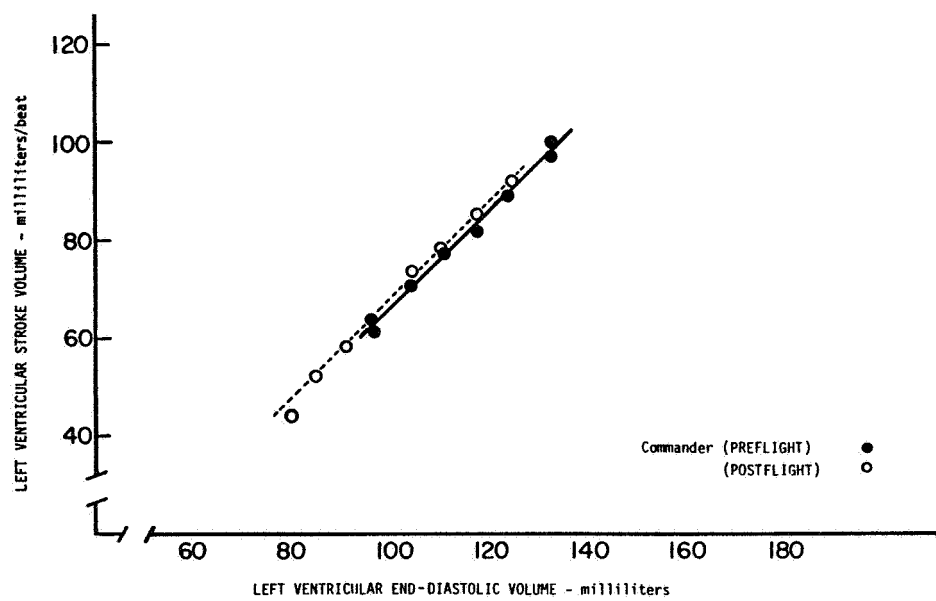


Figure 6. Ventricular Function Curve, Commander of Skylab 4.

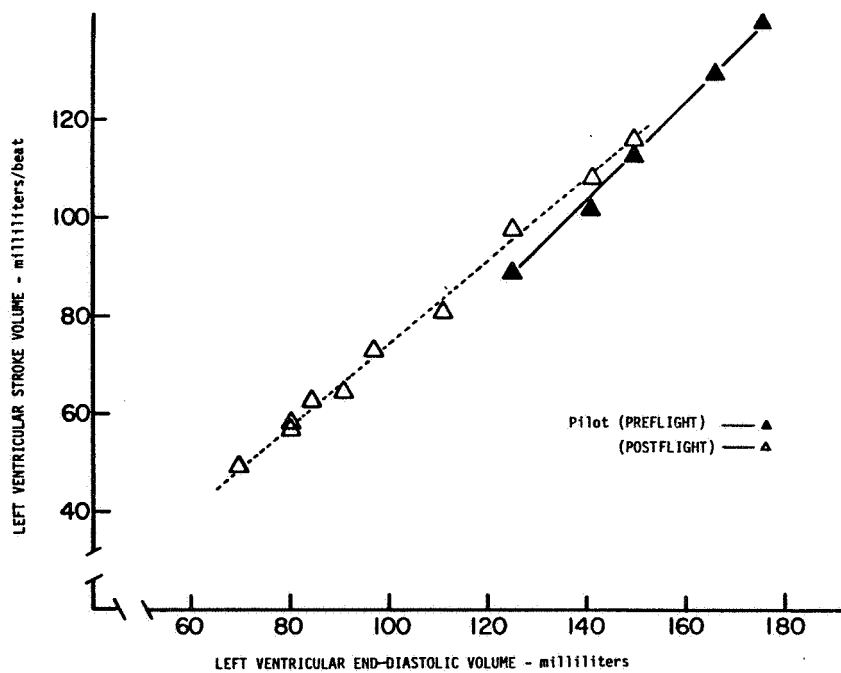


Figure 7. Ventricular function curve, Pilot of Skylab 4

DISCUSSION

The results of the present investigation demonstrate that small but significant decreases in stroke volume occurred in two of the three Skylab 4 astronauts immediately following an 84-day period of weightlessness. Although this could be interpreted as an impairment of cardiac function, echocardiographic measurements demonstrated that left ventricular end-diastolic volume also was slightly diminished postflight in the same two astronauts. Since end-diastolic volume is an important determinant of stroke volume, it is obvious that comparisons of parameters of cardiac performance must be made at comparable end-diastolic volumes. When this was done (by constructing ventricular function curves), it was clear that no significant alteration in cardiac *function* occurred in any astronaut. Moreover, the small decreases in left ventricular end-diastolic volume, stroke volume and left ventricular mass that did occur were demonstrated to be reversible postflight over a 30-day period.

It is interesting to speculate on the mechanism of the alterations in left ventricular volume and mass seen in the Skylab 4 astronauts. One mechanism that could account for the dimensional changes is the profound change in plasma volume that occurs with weightlessness (1). The mechanism undoubtedly explains at least some of the changes observed in left ventricular end-diastolic volume. However, it is possible that other factor(s) are involved. Of interest, the two astronauts (Scientist Pilot and Pilot) in whom decreases in left ventricular end-diastolic volumes were observed had end-diastolic volumes preflight that were significantly greater than the usually accepted normal range. In this regard, echocardiographic data of the Scientist Pilot and Pilot were very similar to those seen in trained athletes involved in endurance events (*i.e.*, swimmers, runners) (11) in that the echocardiograms of such athletes reveal a dilated, nonthickened left ventricle that ejects an increased stroke volume. In contrast, the left ventricular end-diastolic volume and stroke volume of the Commander were at the upper limits of normal. Of note, the Scientist Pilot and Pilot ran much longer distances during their preflight training than the Commander. If these differences in cardiac dimensions are due to the differences in the amount of preflight distance running performed by the three astronauts, then it is possible that at least some of the changes seen immediately following the 84-day space mission merely reflect the inability to continue distance running while in space. It should be emphasized that despite the decreases in left ventricular dimensions observed in the Scientist Pilot and Pilot immediately postflight, their echocardiograms postflight were still in the trained athlete range, and the Commander was still at the upper limit of normal. That more striking changes did

not occur may be at least partly a result of the bicycle exercises performed in space during the 84-day mission.

While the results of the present study cannot be extrapolated to longer duration space missions, it is clear that 84 days of weightlessness did not produce any deterioration in cardiac function. Moreover, the changes in cardiac volume and mass observed were minimal and reversible. The data indicate that the cardiovascular system adapts well to prolonged weightlessness and suggest that alterations in cardiac dimensions and function are unlikely to limit man's future in space.

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